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(54) **INTEGRATED DISPLAY AND PHOTOSENSOR**

(75) Inventors: **Babak Amirparviz**, Mountain View, CA (US); **Chia-Jean Wang**, Palo Alto, CA (US)

(73) Assignee: **Google Inc.**, Mountain View, CA (US)

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(51) **Int. Cl.**

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G02B 27/00	(2006.01)
G06F 3/01	(2006.01)
G09G 3/00	(2006.01)
G02B 27/01	(2006.01)
G09G 3/34	(2006.01)

(52) **U.S. Cl.**

CPC ***G02B 27/0093*** (2013.01); ***G02B 27/0172*** (2013.01); ***G06F 3/013*** (2013.01); ***G09G 3/001*** (2013.01); ***G09G 3/346*** (2013.01); *G02B 2027/0138* (2013.01); *G02B 2027/0178* (2013.01); *G02B 2027/0187* (2013.01); *G09G 3/3413* (2013.01); *G09G 2354/00* (2013.01); *G09G 2360/14* (2013.01); *G09G 2370/027* (2013.01)

(58) **Field of Classification Search**

CPC G02B 6/00; G02B 26/00; G02B 27/017; G02B 27/0093; G02B 2027/0178; G02B 2027/0187; G06F 3/013; G09G 2360/14; G09G 2360/142; G09G 3/3413; G09G 3/001; G09G 3/346; G09G 2370/027

See application file for complete search history.

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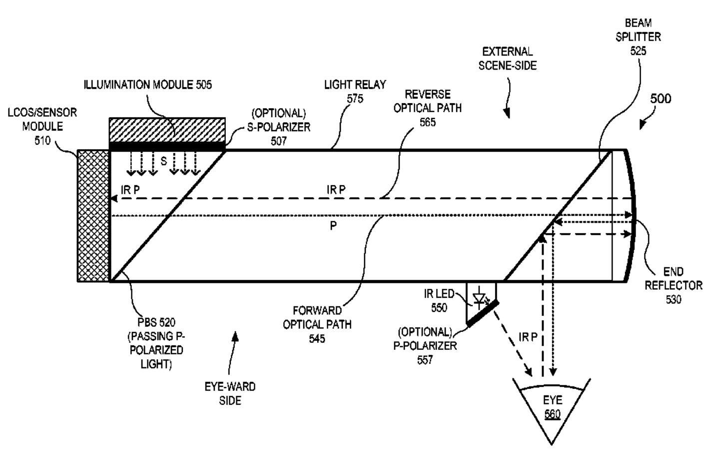
Primary Examiner — Linh N Hoffner

(74) *Attorney, Agent, or Firm* — Blakely Sokoloff Taylor & Zafman LLP

(57) **ABSTRACT**

An apparatus for simultaneously imaging a subject and displaying computer generated image ("CGI") light to the subject includes a display array and a photodetector array. The display array and the photodetector array are disposed on a same semiconductor die. The display array includes display pixels configured to selectively generate the CGI light to be sent along a forward optical path. The photodetector array is positioned to receive non-visible image light that is reflected by the subject and directed along a reverse optical path. The CGI light to be sent along the forward optical path travels in a substantially opposite direction as the non-visible image light directed along the reverse optical path.

24 Claims, 8 Drawing Sheets



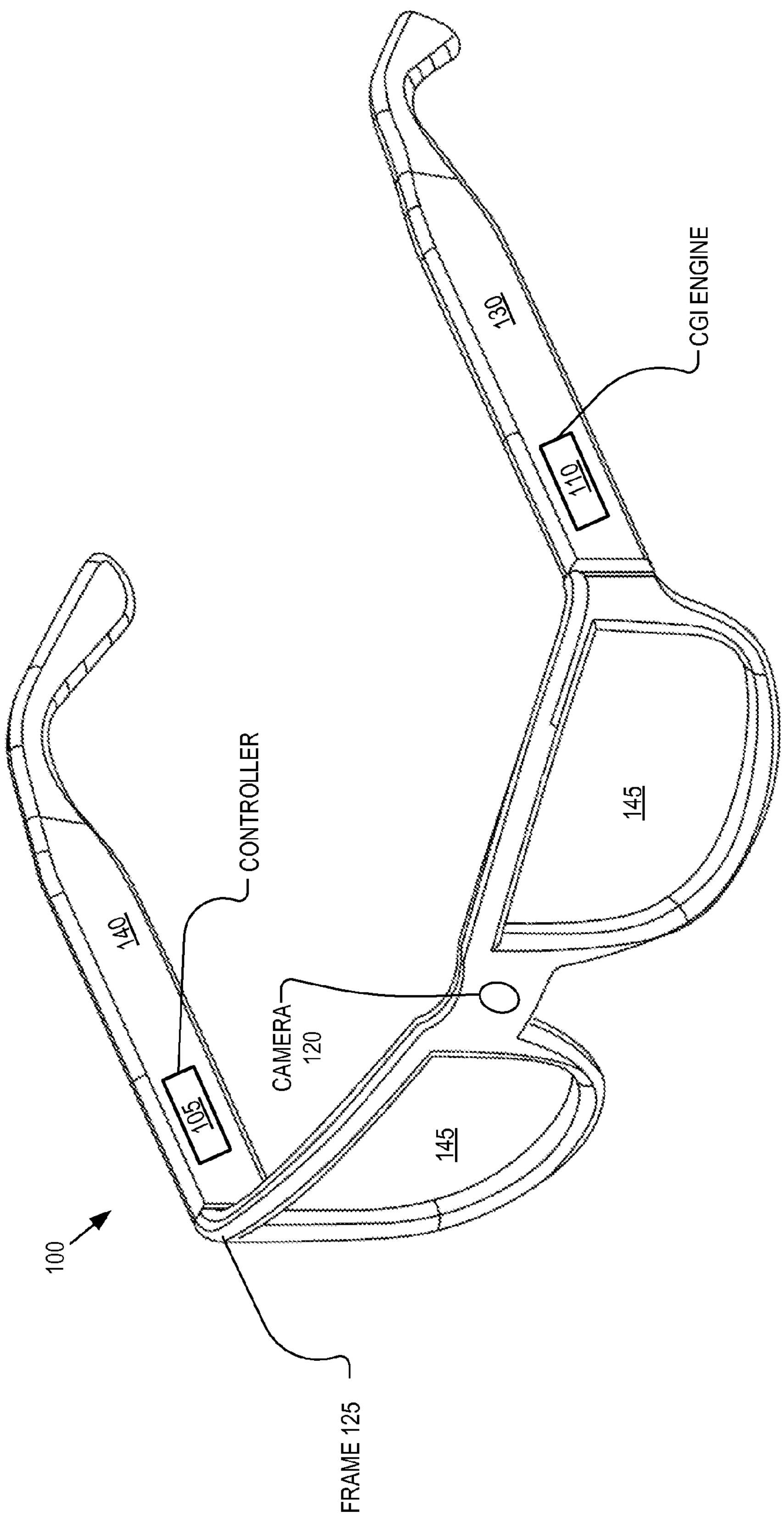

CGI ENGINE
130
110
145
145
CONTROLLER
140
105
CAMERA
120
100
FRAME 125

FIG. 1

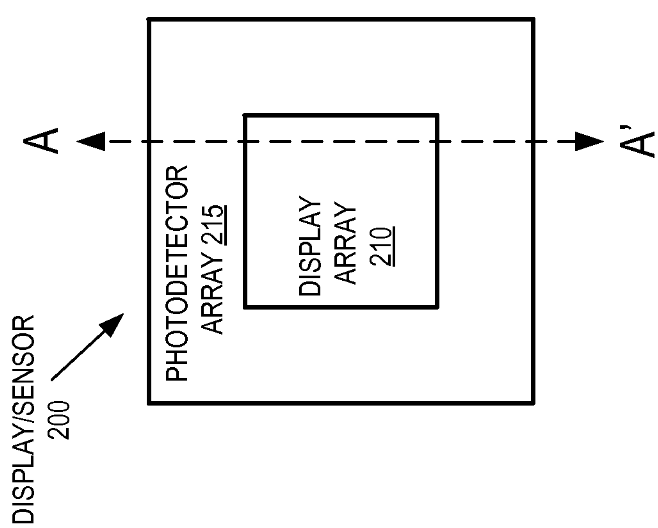

DISPLAY/SENSOR
200
PHOTODETECTOR
ARRAY 215
DISPLAY
ARRAY
210
A
A'

FIG. 2A

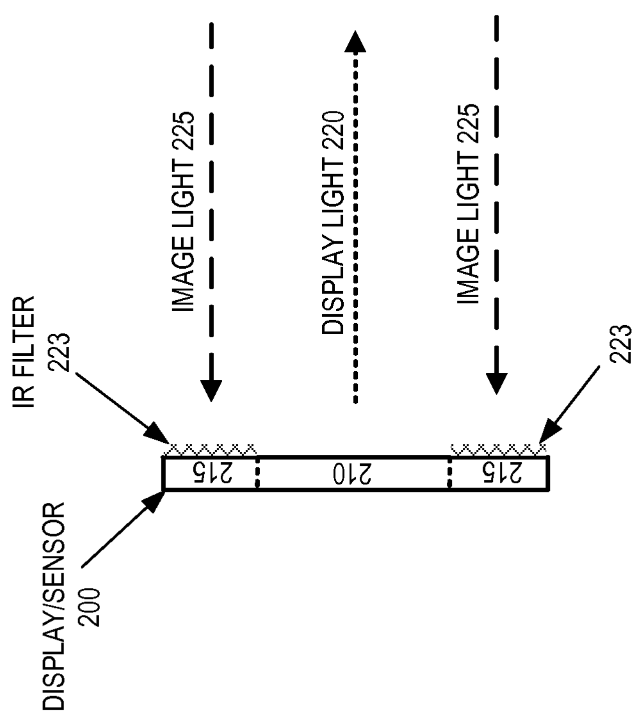

DISPLAY/SENSOR
200
IR FILTER
223
IMAGE LIGHT 225
DISPLAY LIGHT 220
IMAGE LIGHT 225
223
215
210
215

FIG. 2B

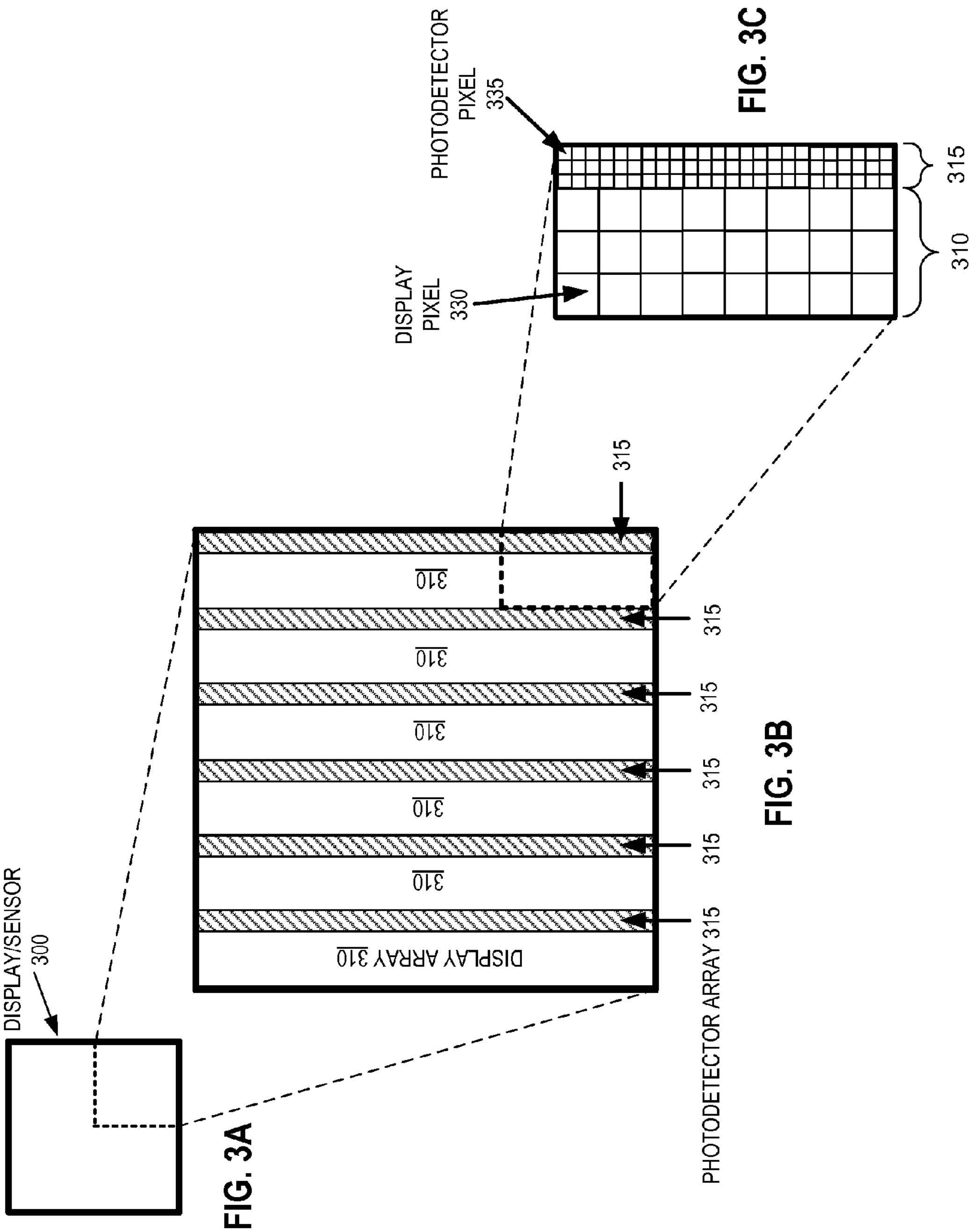


FIG. 3A

FIG. 3B

FIG. 3C

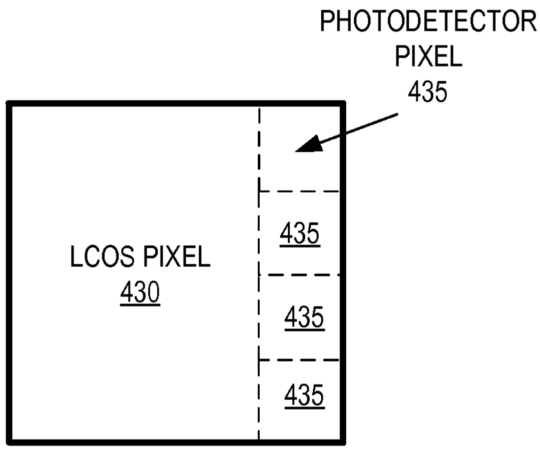

PHOTODETECTOR
PIXEL
435
LCOS PIXEL
430
435
435
435

FIG. 4A

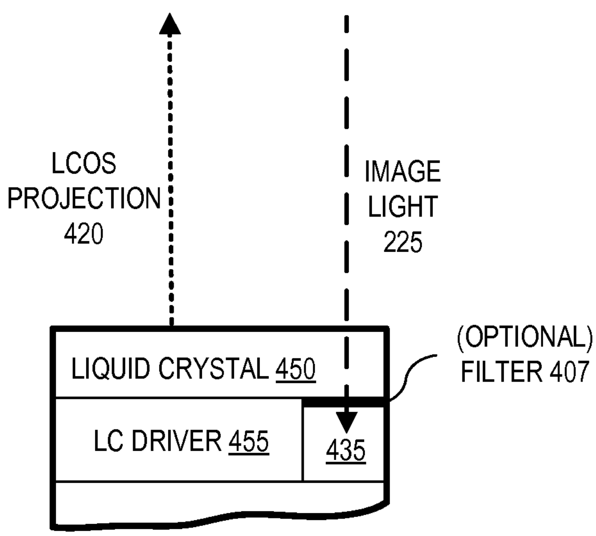

LCOS
PROJECTION
420
IMAGE
LIGHT
225
(OPTIONAL)
FILTER 407
LIQUID CRYSTAL 450
LC DRIVER 455
435

FIG. 4B

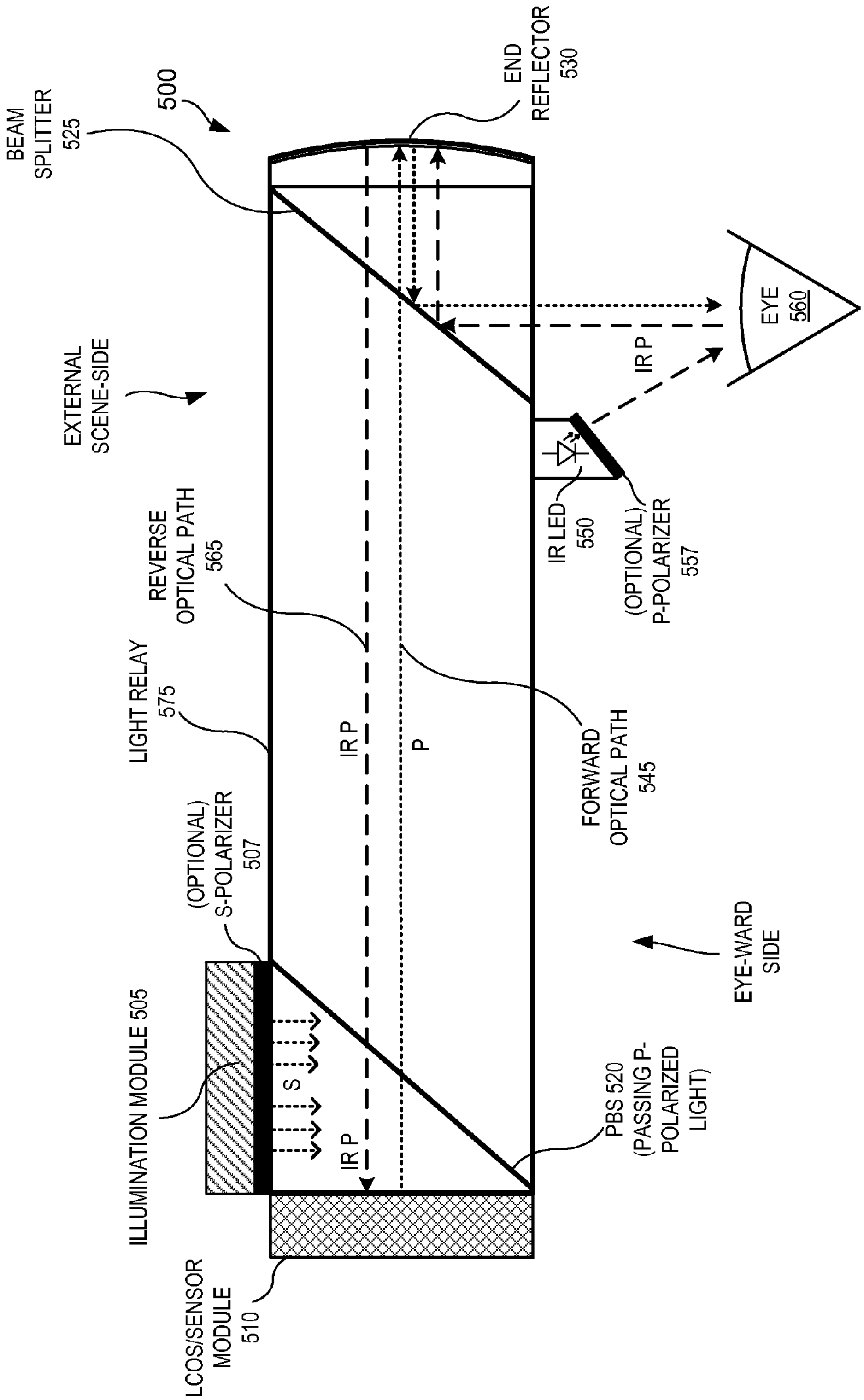

500
BEAM SPLITTER 525
END REFLECTOR 530
EXTERNAL SCENE-SIDE
EYE 560
IR P
IR LED 550
(OPTIONAL) P-POLARIZER 557
REVERSE OPTICAL PATH 565
LIGHT RELAY 575
IR P
P
FORWARD OPTICAL PATH 545
(OPTIONAL) S-POLARIZER 507
EYE-WARD SIDE
ILLUMINATION MODULE 505
S
IR P
PBS 520 (PASSING P-POLARIZED LIGHT)
LCOS/SENSOR MODULE 510

FIG. 5

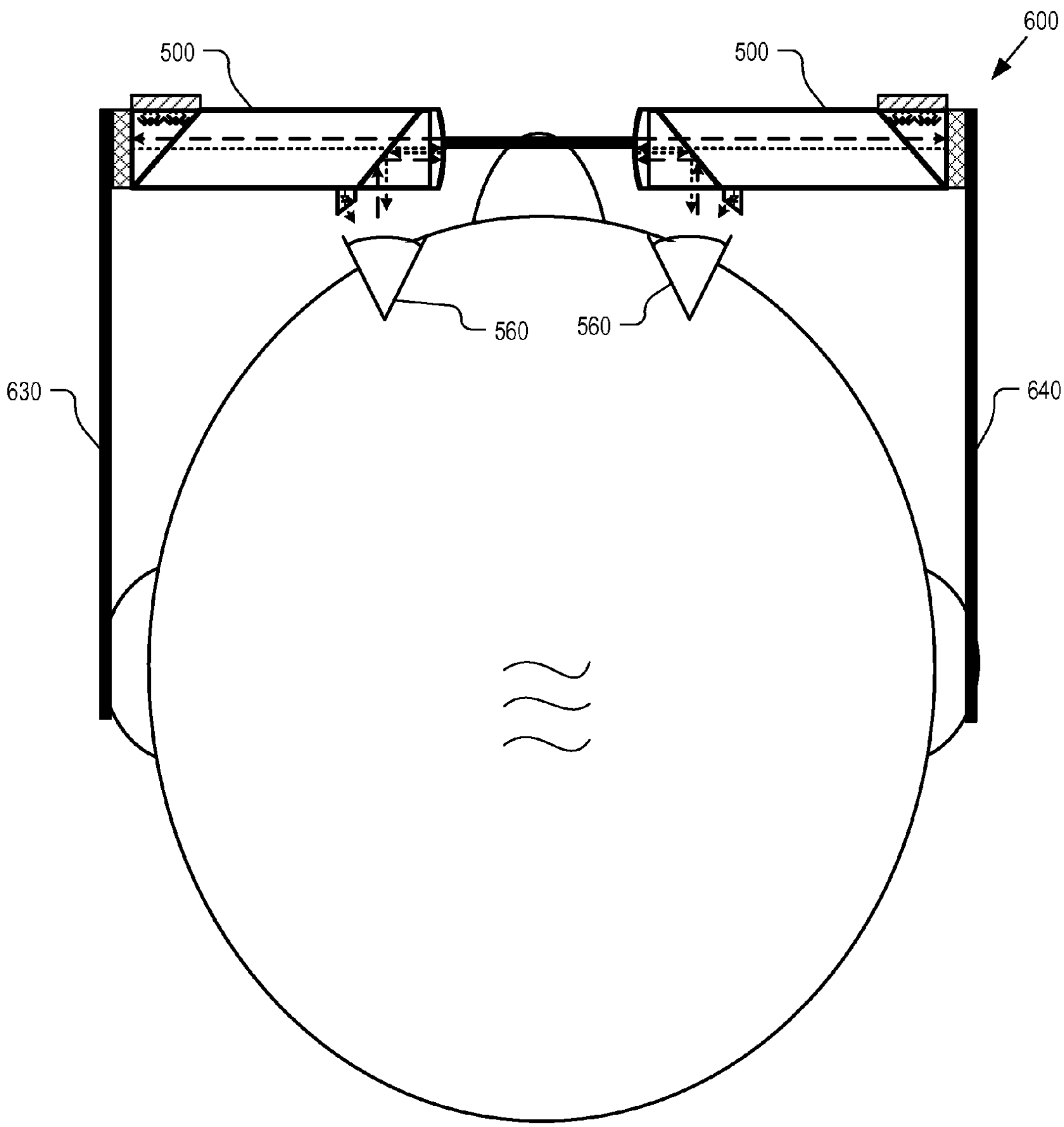


FIG. 6

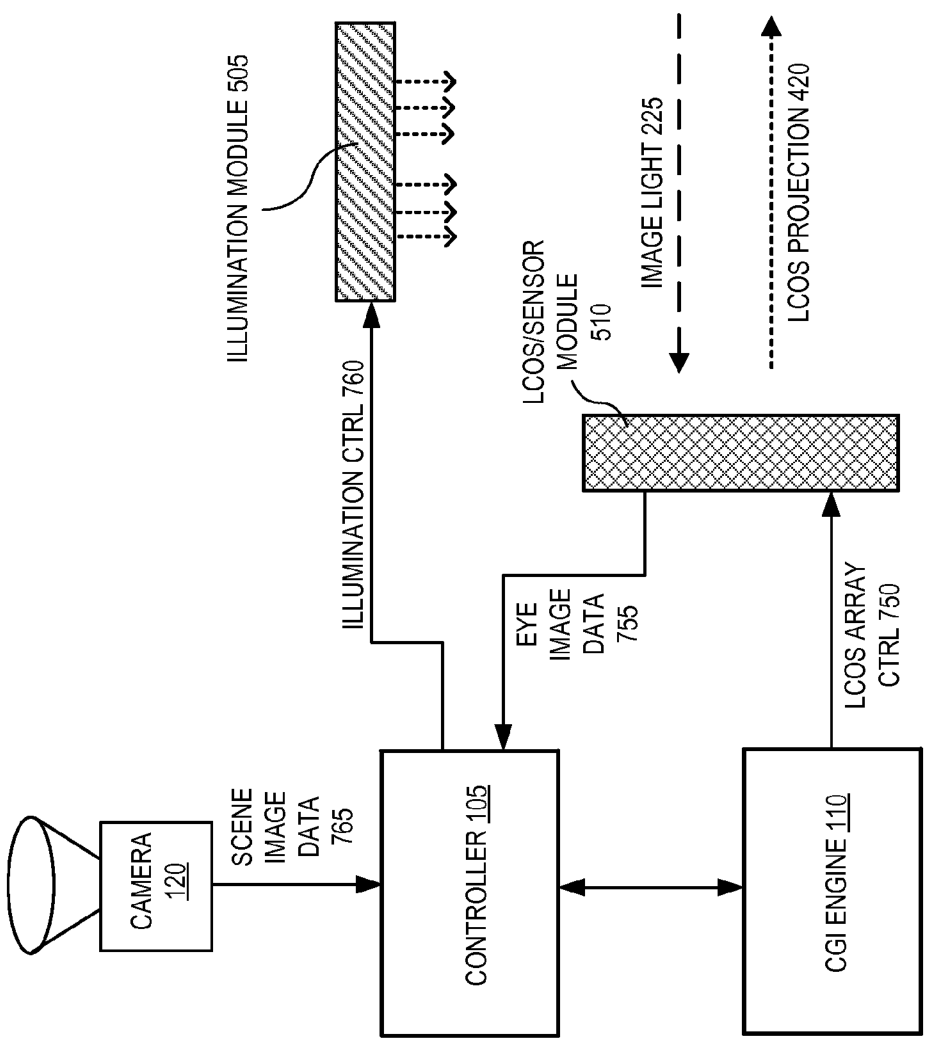

ILLUMINATION MODULE 505
IMAGE LIGHT 225
LCOS PROJECTION 420
LCOS/SENSOR MODULE 510
ILLUMINATION CTRL 760
EYE IMAGE DATA 755
LCOS ARRAY CTRL 750
CAMERA 120
SCENE IMAGE DATA 765
CONTROLLER 105
CGI ENGINE 110

FIG. 7

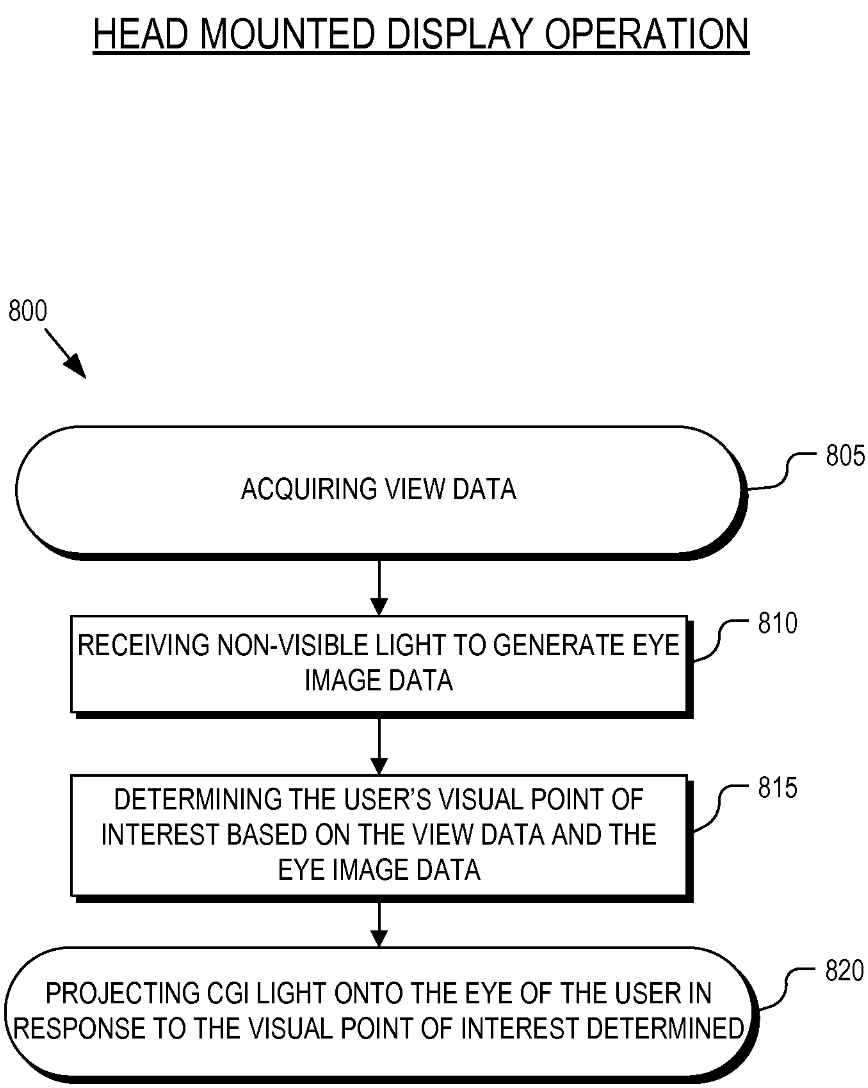

HEAD MOUNTED DISPLAY OPERATION
800
ACQUIRING VIEW DATA
805
RECEIVING NON-VISIBLE LIGHT TO GENERATE EYE IMAGE DATA
810
DETERMINING THE USER'S VISUAL POINT OF INTEREST BASED ON THE VIEW DATA AND THE EYE IMAGE DATA
815
PROJECTING CGI LIGHT ONTO THE EYE OF THE USER IN RESPONSE TO THE VISUAL POINT OF INTEREST DETERMINED
820

FIG. 8

INTEGRATED DISPLAY AND PHOTOSENSOR

TECHNICAL FIELD

This disclosure relates generally to the field of optics, and in particular but not exclusively, relates to near-to-eye optical systems.

BACKGROUND INFORMATION

A head mounted display ("HMD") is a display device worn on or about the head. HMDs usually incorporate some sort of near-to-eye optical system to emit a light image within a few centimeters of the human eye. Single eye displays are referred to as monocular HMDs while dual eye displays are referred to as binocular HMDs. Some HMDs display only a computer generated image ("CGI"), while other types of HMDs are capable of superimposing CGI over a real-world view. This latter type of HMD can serve as the hardware platform for realizing augmented reality. With augmented reality, the viewer's image of the world is augmented with an overlaying CGI, also referred to as a heads-up display ("HUD").

HMDs have numerous practical and leisure applications. Aerospace applications permit a pilot to see vital flight control information without taking their eye off the flight path. Public safety applications include tactical displays of maps and thermal imaging. Other application fields include video games, transportation, and telecommunications. There is certain to be new found practical and leisure applications as the technology evolves; however, many of these applications are limited due to the cost, size, weight, field of view, and efficiency of conventional optical systems used to implemented existing HMDs.

BRIEF DESCRIPTION OF THE DRAWINGS

Non-limiting and non-exhaustive embodiments of the invention are described with reference to the following figures, wherein like reference numerals refer to like parts throughout the various views unless otherwise specified.

FIG. **1** is a perspective view of wearable glasses for human-computer interaction, in accordance with an embodiment of the disclosure.

FIG. **2**A is a front view of an example integrated display and sensor, in accordance with an embodiment of the disclosure.

FIG. **2**B is a cross-sectional side view through line A-A' of the example integrated display and sensor illustrated in FIG. **2**A, in accordance with an embodiment of the disclosure.

FIGS. **3**A-**3**C are progressively zoomed-in front views of sections of an example integrated display and sensor, in accordance with an embodiment of the disclosure.

FIGS. **4**A and **4**B illustrate an example Liquid Crystal on Silicon pixel overlapping example photodetector pixels, in accordance with an embodiment of the disclosure.

FIG. **5** is a top cross-sectional view of an eyepiece optical system, in accordance with an embodiment of the disclosure.

FIG. **6** is a top view of a user wearing a binocular HMD implanted with eyepieces, in accordance with an embodiment of the disclosure.

FIG. **7** is an example block diagram schematic of components that may be integrated into an HMD, in accordance with an embodiment of the disclosure.

FIG. **8** is a flow chart illustrating a process of operation of an HMD for displaying CGI, in accordance with an embodiment of the disclosure.

DETAILED DESCRIPTION

Embodiments of an integrated display and photosensor apparatus and embodiments of methods of operation for a head mounted display ("HMD") are described herein. In the following description, numerous specific details are set forth to provide a thorough understanding of the embodiments. One skilled in the relevant art will recognize, however, that the techniques described herein can be practiced without one or more of the specific details, or with other methods, components, materials, etc. In other instances, well-known structures, materials, or operations are not shown or described in detail to avoid obscuring certain aspects.

Reference throughout this specification to "one embodiment" or "an embodiment" means that a particular feature, structure, or characteristic described in connection with the embodiment is included in at least one embodiment of the present invention. Thus, the appearances of the phrases "in one embodiment" or "in an embodiment" in various places throughout this specification are not necessarily all referring to the same embodiment. Furthermore, the particular features, structures, or characteristics may be combined in any suitable manner in one or more embodiments.

FIG. **1** is a perspective view of wearable glasses for human-computer interaction, in accordance with an embodiment of the disclosure. The illustrated embodiment of wearable glasses **100** includes lenses **145** disposed in frame **125** that includes left temple arm **130** and right temple arm **140**. Although FIG. **1** illustrates a traditional eyeglass frame **125**, embodiments of the present invention are applicable to a wide variety of frame types and styles (e.g. visor, headband, goggles). Lenses **145** may or may not be corrective lenses with optical power and in some embodiments, may even be omitted.

Wearable glasses **100** may include a controller **105** disposed in right temple arm **140** and a computer generated image ("CGI") engine **110** disposed in left temple arm **130**. Controller **105** and CGI engine **110** may be disposed in other locations in wearable glasses **100**. Controller **105** may include an integrated circuit with hardware, firmware, or software logic. CGI engine **110** may include a processor and graphics engine for rendering image data. In one embodiment, controller **105** and CGI engine **110** are combined in one integrated-chip. Controller **105** may be used to receive, transmit, and process data and communicate with CGI engine **110**. CGI engine **110** may generate images for displaying to the eye of a user. The illustrated embodiment of wearable glasses **100** includes a camera **120** disposed in a bridge of frame **125**. Camera **120** may be forward facing (as illustrated) or located in different locations in frame **125** and more than one camera may be utilized in some embodiments.

FIG. **2**A is a front view of display/sensor **200**, in accordance with an embodiment of the disclosure. Display/sensor **200** may simultaneously image a subject and display CGI light to the subject. Display/sensor **200** includes a display array **210** and a photodetector array **215**. In one embodiment, the subject is a human eye and photodetector array **215** monitors the gaze of the eye and display array **210** displays CGI light to the eye, based on the gaze of the eye.

Display array **210** may include different technologies such as Liquid Crystal on Silicon ("LCOS"), organic light emitting diodes ("OLED"), quantum dots, backlit liquid crystal display ("LCD"), micro mirror projecting technology, or otherwise. Photodetector array **215** may use CMOS photodiodes (e.g. P-N photodiode), but other technologies may be used. In one embodiment, display array **210** and photodetector array **215** are disposed in the same chip package. In one embodiment, display array **210** and photodetector array **215** are disposed on the same semiconductor die or silicon substrate. In the illustrated embodiment, photodetector array **215** surrounds display array **210**. In other embodiments, photodetector array **215** may partially encircle display array **210**, or simply be disposed adjacent to sides of display array **210**.

FIG. **2**B is a cross-sectional side view (through line A-A' of FIG. **2**A) of display/sensor **200**, in accordance with an embodiment of the disclosure. Display array **210** includes display pixels configured to selectively generate CGI light (such as display light **220**) to be sent along a forward optical path. Photodetector array **215** includes photodetector pixels that are positioned to receive light (such as image light **225**) that is reflected by the subject and directed along a reverse optical path. The light traveling along the reverse optical path may travel in an opposite or substantially opposite direction as display light **220** directed along the forward optical path. In one embodiment, the light that the subject reflects (e.g. image light **225**) is non-visible light. The non-visible light may be between 800 and 1000 nm. In one embodiment, IR filter **223** is disposed over photodetector array **215** so that image light **225** must travel through IR filter **223** before reaching photodetector array **215**. IR filter **223** may substantially filter out visible light and substantially pass the non-visible image light to photodetector array **215**. In one embodiment, IR filter **223** is a bandpass filter that substantially passes near-infrared light between 800 and 1000 nm.

FIGS. **3**A-**3**C are progressively zoomed-in front views of sections of display/sensor **300**, in accordance with an embodiment of the disclosure. FIG. **3**B shows an array level zoomed-in view of a section of display/sensor **300**, illustrated in FIG. **3**A. FIG. **3**B illustrates that display/sensor **300** includes a display array **310** and a photodetector array **315** disposed on the same semiconductor die. FIG. **3**B shows display array **310** and photodetector array **315** arranged in a repeating pattern. FIG. **3**B also shows that lines of display array **310** are interlaced with lines of photodetector array **315** in a repeating pattern. The lines may be oriented as columns or as rows. Other repeating patterns are possible. One repeating pattern may include photodetector pixels of photodetector array **315** uniformly distributed amongst display pixels of display array **310**. In one embodiment, photodetector pixels of photodetector array **315** are uniformly distributed amongst display pixels of display array **310** in a checkerboard-like pattern that is repeated on the semiconductor die. It is appreciated that photodetector array **315** may have a different resolution than display array **310**, which may affect the relative distribution of the pixels and the pattern of the pixels.

FIG. **3**C shows a pixel level zoomed-in view of a section of FIG. **3**B. FIG. **3**C shows that display array **310** includes display pixels **330** and that photodetector array **315** includes photodetector pixels **335**. In the illustrated embodiment of FIG. **3**C, the line of display array **310** is three display pixels **330** wide and the line of photodetector array **315** is three photodetector pixels wide. However the lines of display array **310** and photodetector array **315** are not limited to being three pixels wide—each of the lines may be any number of pixels wide, including one pixel wide. In one embodiment, the line of display array **310** is three display pixels **330** wide and the line of photodetector array **315** is one photodetector pixel **335** wide. The arrangement and size of the pixels may be determined by the resolutions of display array **310** and photodetector array **315**.

The display technology may also affect the relative resolution of display array **310**. For example, LCOS technology that requires color filters may be utilized, which may require more display pixels **330**. Color sequential LCOS technology may require fewer display pixels **330**. If the LCOS technology requires color filters and red, green, and blue pixels, display array **310** may have more pixels. Depending on the technology selected (LCOS or otherwise) red, green, and blue filters may be disposed over respective display pixels **330**. If photodetector pixels **335** are configured to detect a specific wavelength or spectrum of light (e.g. non-visible light), filters may be disposed over photodetector pixels **335**. In one embodiment, an IR bandpass filter is used that substantially passes near-infrared light between 800 and 1000 nm. In one embodiment, display pixels **330** are LCOS pixels that are approximately 5-20 μm. Photodetector pixels **335** may be CMOS photodiodes that are approximately 2-5 μm.

FIGS. **4**A and **4**B illustrate an example Liquid Crystal on Silicon pixel overlapping example photodetector pixels, in accordance with an embodiment of the disclosure. FIG. **4**A is a top view of an LCOS pixel **430** overlaying photodetector pixels **435**. LCOS pixel **430** and photodetector pixels **435** are disposed on the same semiconductor (e.g. silicon) substrate in the illustrated embodiment. Photodector pixels **435** are shown with dashed lines in FIG. **4**A to indicate that they are underneath at least a portion of LCOS pixel **430**. LCOS pixel **430** may be in a display array and photodetector pixels **435** may be in a photodetector array. Different arrangements of how many photodetector pixels **435** may be underneath a portion of LCOS pixel **430** are possible. In one embodiment, one photodetector pixel **435** may be underneath more than one LCOS pixel **430**.

FIG. **4**B is a cross-sectional side view of LCOS pixel **430** and photodetector pixel **435**. In the illustrated embodiment, photodetector pixel **435** is disposed under liquid crystal **450** of LCOS pixel **430**. Liquid Crystal ("LC") driver **455** is also disposed under liquid crystal **450** and is disposed adjacent to photodetector pixel **435**. Optionally, filter **407** may be disposed above photodetector pixel **435** so that image light **225** must travel through filter **407** before reaching photodetector pixel **435**. Filter **407** may substantially pass near-infrared light between 800 and 1000 nm. In the illustrated embodiment, LC driver **455** is disposed under a portion of liquid crystal **450** to manipulate liquid crystal **450** according to signals received by LC driver **455**. The signals received by LC driver **455** will cause LCOS pixel **430** to selectively reflect emitted light to generate LCOS projection **420**. It is appreciated that LC driver **455** may only be able to manipulate the portion of liquid crystal **450** above LC driver **455** and that the portion of liquid crystal **450** disposed above photodetector pixel **435** may remain in a substantially unchanged, steady state.

Liquid crystal **450** may influence image light **225** when image light **225** travels through photodetector pixel **435**. A correction may be applied to account for the optical transmission characteristics of liquid crystal **450** that may influence image light **225**. A calibration procedure may be initiated using a known light source to derive the optical transmission characteristics of liquid crystal **450**. A correction factor or equation that accounts for the optical transmission characteristics of liquid crystal **450** may be applied to an image signal that photodetector pixel **435** outputs. The correction may be applied with hardware and/or with firmware/software.

With regard to FIGS. **2**A-**4**B, it is appreciated that a light source (not shown) may emit visible illumination light to be provided to display array **210**, **310**, or an array of LCOS pixels **430** when the respective display arrays include a reflective display technology, such as LCOS or micro mirrors. The visible illumination light may be directed to the display arrays by mirrors. A lens or a series of lenses may be disposed between a light source and the one of the display arrays. The light source may include a red-green-blue light emitting diode ("RGB LED") contained in one chip package. Alternatively, the light source may include, separate, discrete red, green and blue LEDs. The light source may include a white LED or a series of white LEDs. The LEDs may be arranged in series strings or in parallel. In one embodiment, modulation circuitry is configured to individually strobe each color (RGB) of the LEDs.

Furthermore, a second light source (not shown) may be positioned to emit light onto the subject to provide light that can be reflected by the subject and received by photodetector array **215**, **315**, or an array of photodetector pixels **435**. In one embodiment, the second light source emits non-visible light onto the subject. The light emitted by the second light source may encounter filters, mirrors, and/or lenses before being directed toward one of the photodetector arrays.

FIG. **5** is a top cross-sectional view of an eyepiece optical system, in accordance with an embodiment of the disclosure. Eyepiece **500** may be integrated into wearable glasses **100**. The illustrated embodiment of eyepiece **500** includes an illumination module **505**, optional s-polarizer **507**, an LCOS/sensor module **510**, and a light relay **575**. Eyepiece **500** also includes a polarizing beam splitter ("PBS") **520**, a beam splitter **525**, an end reflector **530**, and an IR LED **550** with an optional p-polarizer **557**. Light relay **575** is also included in eyepiece **500**.

In the illustrated embodiment, illumination module **505** is disposed on an external scene-side of eyepiece **500**. Illumination module **505** includes a light source that may be implemented with a light emitting diode ("LED"), a laser, bulb, or otherwise. If the light source is LED based, the light source may include a red-green-blue light emitting diode ("RGB LED") contained in one chip package. Alternatively, the light source may include, separate, discrete red, green, and blue LEDs. The light source may include a white LED or a series of white LEDs. The LEDs may be arranged in series strings or in parallel. In one embodiment, modulation circuitry is configured to individually strobe each color (RGB) of the LEDs. Illumination module **505** may include diffuse filters or other optical schemes to more uniformly distribute the light emitted by illumination module **505**.

Optionally, s-polarizer **507** may be included in illumination module **505** so that illumination module **505** emits light with a specific polarization orientation. S-polarizer **507** is an example filter that could be included in illumination module **505**, but it is appreciated that s-polarizer **507** could be exchanged for a filter that emits light of a different polarization orientation (e.g. p-polarization orientation) if corresponding adjustments are made to other components in eyepiece **500**. In one embodiment, illumination module **505** does not have a polarizing filter.

In the illustrated embodiment, LCOS/sensor module **510** is disposed on a side of eyepiece **500** that is approximately perpendicular to the external scene-side of eyepiece **500**. LCOS/sensor module **510** includes an LCOS array and a photodetector array. The layouts of display/sensor **200** and **300** and the embodiment described above in connection with FIGS. **2A-3C** may be incorporated into LCOS/sensor module **510**. Additionally, embodiments of LCOS pixel **430** and photodetector pixels **435** as discussed in connection with FIGS. **4A-4B** may be included in LCOS pixels in the LCOS array of LCOS/sensor module **510**. The LCOS array of LCOS/sensor module **510** includes LCOS pixels configured to selectively generate CGI light to be sent along forward optical path **545** toward end reflector **530**. Photodetector pixels of a photodetector array within LCOS/sensor module **510** are positioned to receive infrared or near-infrared light that is reflected by eye **560** and directed along reverse optical path **565**.

Light relay **575** has a transparent structure to permit the CGI light along forward optical path **545** to pass through light relay **575**. Light relay **575** may be fabricated of a solid transparent material (e.g., glass, quartz, acrylic, clear plastic, PMMA, ZEONEX—E48R, etc.) or be implemented as a solid housing having an inner air gap through which the CGI light passes. Light relay **575** operates to protect the optical paths, but may not use total internal reflection ("TIR") to guide or confine the CGI light. In one embodiment (not shown), light relay **575** is curved.

PBS **520** is positioned to direct the light emitted by illumination module **505** towards LCOS/sensor module **510**. PBS **520** passes p-polarized light and reflects s-polarized light, in the illustrated embodiment. It is appreciated that PBS **520** could be configured to pass a different polarization orientation if corresponding adjustments were made to other components in eyepiece **500**. In the illustrated embodiment, beam splitter **525** is disposed within eyepiece **500** between PBS **520** and end reflector **530**. In one embodiment, beam splitter **525** is a 50/50 beam splitter that passes 50% of light and reflects 50% of light, although other percentages are possible. Beam splitter **525** allows eye **560** to see light from the external scene-side of eyepiece **500**, while beam splitter **525** is also capable of assisting in directing CGI light to eye **560** of a user of eyepiece **500**. In one embodiment, a fixed polarization rotator is disposed between beam splitter **525** and end reflector **530** and beam splitter **525** is a polarization beam splitter. The fixed polarization rotator may be a one-quarter wavelength rotator or quarter wave plate, which rotates light approximately 45 degrees. End reflector **530** is disposed at an opposite end of LCOS/sensor module **510**. In the illustrated embodiment, end reflector **530** is a concave mirror.

In the illustrated embodiment, light displayed to eye **560** starts as s-polarized light emitted from illumination module **505**. Since PBS **520** passes p-polarized light and reflects s-polarized light, PBS **520** directs the s-polarized emitted light to the LCOS array of LCOS sensor module **510**. (If the s-polarizer **507** is not included in illumination module **505**, a p-polarized portion of the emitted light would be passed to the eye-ward side of eyepiece **500**). The LCOS pixels in the LCOS array selectively reflect the s-polarized emitted light to generate CGI light to be sent along forward optical path **545**. Still referring to the illustrated embodiment, the s-polarized emitted light is rotated 90 degrees to p-polarized light by the LCOS array in LCOS/sensor module **510**. Hence, the CGI light sent along forward optical path **545** is p-polarized CGI light, as notated in FIG. **5**.

The p-polarized CGI light encounters beam splitter **525** along forward optical path **545** and a portion (e.g. 50%) of the p-polarized CGI light is directed toward the external scene-side of eyepiece **500**, while a portion (e.g. 50%) of the p-polarized CGI light is passed toward end reflector **530**. It is appreciated that not all of the light paths (e.g. CGI light directed by beam splitter **525** toward the external scene-side of eyepiece **500**) are shown in FIG. **5**, as to not obscure the invention. The p-polarized CGI light passed by beam splitter **525** reflects off end reflector **530** and encounters beam splitter **525** which directs a portion of the p-polarized CGI light toward eye **560**, while the other portion is passed by beam splitter **525**.

Light imaged by a photodetector array of LCOS/sensor module **510** may start as near-infrared p-polarized light emitted by IR LED **550**, in the illustrated embodiment. The near-infrared p-polarized light emitted by IR LED **550** reflects off of eye **560** toward beam splitter **525**. The eye-reflected p-polarized light encounters beam splitter **525** and a portion (e.g. 50%) of the p-polarized light is passed to the external scene-side of eyepiece **500**, while a portion (e.g. 50%) of the p-polarized light is directed toward end reflector **530**. The eye reflected p-polarized light directed toward end reflector **530** reflects off end reflector **530** and a portion is directed toward the eye-ward side of eyepiece **500** by beam splitter **525**, while the other portion is passed by beam splitter **525**, and continues along reverse optical path **565**. The eye reflected p-polarized light then encounters PBS **520**, which passes the eye reflected p-polarized light to the photodetector array of LCOS/sensor module **510**. The eye-reflected light passed by PBS **520** may travel through an infrared filter similar to IR filter **223** before being received by the photodetector array of LCOS/sensor module **510**. In one embodiment, the filter is a bandpass filter that substantially passes near-infrared light between 800 and 1000 nm and IR LED **550** emits light approximately centered at 950 nm.

FIG. **6** is a top view of a user wearing a binocular HMD implanted with eyepieces **500**, in accordance with an embodiment of the disclosure. HMD **600** includes left temple arm **630** and right temple arm **640** positioned above the user's ears. Eyepieces **500** are positioned to project CGI light into eyes **560** of a user of the HMD and to image the eye of the user using LCOS/sensor module **510**. Although FIG. **6** illustrates a binocular HMD having two of eyepiece **500**, one for each eye **560**, an HMD may also be implemented as a monocular HMD including only a single eyepiece positioned to project CGI to, and image, a single eye **560**. And, HMD **600** is illustrated as being implanted with eyepieces **500**, however, an HMD may be implanted with eyepieces that incorporate alternative technologies discussed in the FIGS. **2**A-**4**B that may not be present in the illustrated embodiment of eyepiece **500**.

FIG. **7** is an example block diagram schematic of components that may be integrated into an HMD, in accordance with an embodiment of the disclosure. FIG. **7** shows controller **105** configured to receive scene image data **765** from camera **120**. It is appreciated that scene image data **765** may flow through intermediate electronic components (not shown) between camera **120** and controller **105**. Camera **120** may be a forward facing camera of the HMD oriented to monitor a field of view seen by the user. In the illustrated embodiment, controller **105** is configured to receive eye image data **755** from the photodetector array in LCOS/sensor module **510**. Eye image data **755** is based on the display array of LCOS/sensor module **510** receiving image light **225**. It is appreciated that eye image data **755** may flow through intermediate electronic components (not shown) between LCOS/sensor module **510** and controller **105**. Other display/sensor modules discussed in this disclosure may be used in place of LCOS/sensor module **510** to provide eye image data **755** to controller **105**.

In the illustrated embodiment, controller **105** may be further configured to control the LCOS array of LCOS/sensor module **510**. As shown, controller **105** may control the LCOS array through CGI engine **110**. CGI engine **110** may generate images at the direction of controller **105** for displaying to the eye of a user with the LCOS array of LCOS/sensor module **510**. The LCOS array of LCOS/sensor module **510** may receive LCOS array CTRL **750** from CGI engine **110** or directly from controller **105**. The LCOS array of LCOS/sensor module **510** reflects light from illumination module **505** as LCOS projection **420**.

Controller **105** may be further configured to control illumination module **505**. In the illustrated embodiment, illumination module **505** receives illumination CTRL **760** from controller **105**. Controller **105** may direct strobing of LEDs included in illumination module **505**. Controller **105** may direct the on-times of RGB LEDs included in illumination module **505**. In one embodiment, controller **105** coordinates the illumination of LEDs in illumination module **505** with the LCOS array in LCOS/sensor module **510**.

FIG. **8** is a flow chart illustrating a process **800** of operation of an HMD for displaying CGI, in accordance with an embodiment of the disclosure. The order in which some or all of process blocks appear in process **800** should not be deemed limiting. Rather, one of ordinary skill in the art having the benefit of the present disclosure will understand that some of the process blocks may be executed in a variety of orders not illustrated, or even in parallel.

In process block **805**, view data corresponding to a field of view of a user of the HMD is acquired. In process block **810**, non-visible light reflected off of an eye of a user of the HMD is received to generate eye image data (e.g. eye image data **755**). In process block **815**, a visual point of interest of the user is determined in response to the view data and the eye image data. In process block **820**, refreshed CGI light is projected onto the eye of the user in response to the visual point of interest determined. An LCOS array disposed on the same semiconductor die as the photodetector array may project the refreshed CGI onto the eye of the user of the HMD.

In one embodiment, control circuitry (e.g. controller **105**) receives eye image data from the photodetector array imaging the eye of the user. The controller may determine a visual point of interest of the user in response to analyzing eye image data (e.g. eye image data **755**) combined with analyzing the existing CGI projected onto the eye of the user. (Existing CGI is CGI that is presently, or has been previously, projected onto the eye of the user). For example, if the user is reading a webpage displayed to the user using CGI light, the eye image data combined with data from the existing CGI may allow a controller (e.g. controller **105**) to determine where the gaze of the user is directed on the webpage. The controller may determine a displayed hyperlink on the webpage is a visual point of interest of the user. Controller **105** may then direct CGI engine **110** to generate refreshed CGI to be displayed by the LCOS array. The refreshed CGI may be the exact same CGI that was previously projected, or the refreshed CGI may be different. For example, the refreshed CGI may include information corresponding to the displayed hyperlink or a webpage corresponding to the hyperlink, if the hyperlink is determined as the visual point of interest. In a similar way, the controller may be able to determine when the user is at the bottom of a webpage or document and automatically scroll the page for the user to display new material to the user.

In one embodiment, the controller may determine a visual point of interest (e.g. a restaurant sign) of the user in response to analyzing scene image data (e.g. scene image data **765**) from a camera combined with the eye image data from a photodetector array. Controller **105** may then direct CGI engine **110** to generate refreshed CGI to be displayed by the LCOS array. The refreshed CGI may be the same CGI as previously projected. Or, the refreshed CGI may be different by including information (e.g. restaurant menu) about the visual point of interest.

If the LCOS array includes the configuration discussed above in connection with FIGS. **4**A-**4**B, a correction may be applied to eye image data (e.g. eye image data **755**) to assist in determining the user's visual point of interest. The correction may be based on a transmission characteristic of the liquid crystal of the LCOS pixels. The correction may be applied in hardware and/or firmware/software running on controller **105**.

The processes explained above are described in terms of computer software and hardware. The techniques described may constitute machine-executable instructions embodied within a tangible or non-transitory machine (e.g., computer) readable storage medium, that when executed by a machine will cause the machine to perform the operations described. Additionally, the processes may be embodied within hardware, such as an application specific integrated circuit ("ASIC") or otherwise.

A tangible non-transitory machine-readable storage medium includes any mechanism that provides (i.e., stores) information in a form accessible by a machine (e.g., a computer, network device, personal digital assistant, manufacturing tool, any device with a set of one or more processors, etc.). For example, a machine-readable storage medium includes recordable/non-recordable media (e.g., read only memory (ROM), random access memory (RAM), magnetic disk storage media, optical storage media, flash memory devices, etc.).

The above description of illustrated embodiments of the invention, including what is described in the Abstract, is not intended to be exhaustive or to limit the invention to the precise forms disclosed. While specific embodiments of, and examples for, the invention are described herein for illustrative purposes, various modifications are possible within the scope of the invention, as those skilled in the relevant art will recognize.

These modifications can be made to the invention in light of the above detailed description. The terms used in the following claims should not be construed to limit the invention to the specific embodiments disclosed in the specification. Rather, the scope of the invention is to be determined entirely by the following claims, which are to be construed in accordance with established doctrines of claim interpretation.

What is claimed is:

1. An apparatus for simultaneously imaging a subject and displaying computer generated image ("CGI") light to the subject, the apparatus comprising:

- a Liquid Crystal on Silicon ("LCOS") display disposed on a semiconductor die, wherein the LCOS display includes LCOS pixels configured to selectively generate the CGI light to be sent along a forward optical path;
- a photodetector array disposed on the semiconductor die and positioned to receive non-visible image light directed along a reverse optical path, wherein the non-visible image light is reflected by the subject and travels along the reverse optical path in a substantially opposite direction as the CGI light to be sent along the forward optical path; and
- a filter element disposed in the reverse optical path for substantially filtering out visible light and substantially passing the non-visible image light to the photodetector array, wherein the non-visible image light directed along the reverse optical path travels through at least a portion of one of the LCOS pixels before reaching one of the photodetector pixels.

2. The apparatus of claim **1**, wherein photodetector pixels of the photodetector array and the LCOS pixels are arranged in a repeating pattern on the semiconductor die.

3. The apparatus of claim **2**, wherein the repeating pattern includes the photodetector pixels uniformly distributed amongst the LCOS pixels.

4. The apparatus of claim **2**, wherein the repeating pattern includes columns of the photodetector array interlaced with columns of the LCOS pixels.

5. The apparatus of claim **1**, wherein the photodetector array substantially surrounds the LCOS display.

6. The apparatus of claim **1** further comprising a first light source positioned to provide the illumination light to the LCOS display.

7. The apparatus of claim **6**, wherein the first light source includes a red-green-blue light emitting diode ("RGB LED") and modulation circuitry configured to individually strobe each color of the RGB LED.

8. The apparatus of claim **1** further comprising a second light source positioned to emit the non-visible image light onto the subject.

9. An apparatus for a head mounted display ("HMD"), the apparatus comprising:

- a first light source for providing illumination light;
- a Liquid Crystal on Silicon ("LCOS") array disposed on a semiconductor die, wherein LCOS pixels of the LCOS array are configured to selectively reflect the illumination light provided by the first light source to generate computer generated image ("CGI") light to be sent along a forward optical path within an eyepiece;
- a second light source oriented to emit non-visible light in an eyeward direction of the HMD;
- a photodetector array disposed on the semiconductor die and positioned to receive a reflection of the non-visible light emitted in the eyeward direction, the reflection directed along a reverse optical path in the eyepiece in a substantially opposite direction as the CGI light along the forward optical path;
- an end reflector disposed at an opposite end of the eyepiece from the LCOS array;
- a polarizing beam splitter positioned to direct the illumination light to the LCOS array and disposed within the eyepiece between the end reflector and the LCOS array; and
- a beam splitter for directing the reflection of the non-visible light along the reverse optical path in the eyepiece, the beam splitter disposed within the eyepiece between the polarizing beam splitter and the end reflector.

10. The apparatus of claim **9** further comprising a fixed polarization rotator disposed between the beam splitter and the end reflector, wherein the beam splitter is a polarization beam splitter.

11. The apparatus of claim **9**, wherein photodetector pixels of the photodetector array and the LCOS pixels are arranged in a repeating pattern on the semiconductor die, and wherein the repeating pattern includes the photodetector pixels uniformly distributed amongst the LCOS pixels.

12. The apparatus of claim **9**, wherein first lines of photodetector pixels of the photodetector array are interlaced with second lines of the LCOS pixels, in a repeating pattern on the semiconductor die.

13. The apparatus of claim **9**, wherein the reflection travels through liquid crystal of the LCOS pixels before reaching photodetector pixels of the photodetector array.

14. The apparatus of claim **9**, further comprising a polarizing filter disposed over the second light source for polarizing the non-visible light.

15. The apparatus of claim **9**, wherein the non-visible light is substantially near-infrared light centered between 800 and 1000 nm.

16. The apparatus of claim **9**, wherein the eyepiece is mounted to a frame assembly of the HMD, the frame assembly including a forward facing camera oriented to monitor a field of view seen by an eye of a user of the HMD.

17. The apparatus of claim **16**, further comprising control circuitry configured to receive eye image data generated from the photodetector array and scene image data generated from the forward facing camera, wherein the control circuitry is further configured to control the LCOS array.

18. A method of operating a head mounted display ("HMD"), the method comprising:

acquiring view data corresponding to a field of view of a user of the HMD;

receiving non-visible light reflected off of an eye of the user of the HMD to generate eye image data;

determining a visual point of interest of the user based on the view data and the eye image data; and

projecting refreshed computer generated image ("CGI") light from a Liquid Crystal on Silicon ("LCOS") array onto the eye of the user based on the visual point of interest, wherein a photodetector array receives the non-visible light and the photodetector array and the LCOS array are both disposed on a same semiconductor die, and wherein the non-visible light reflected off of the eye of the user travels through liquid crystal of the LCOS array before being received by the photodetector array.

19. The method of claim **18**, wherein the view data includes existing CGI projected onto the eye of the user from the LCOS array, wherein the existing CGI is presently, or has been previously, projected onto the eye of the user.

20. The method of claim **19** further comprising:

controlling a CGI engine to create a new CGI in response to determining the visual point of interest of the user, wherein the new CGI is for projecting as the refreshed CGI light.

21. The method of claim **18**, wherein the view data includes scene images from a camera of the HMD oriented to monitor a forward view seen by the user.

22. The method of claim **21** further comprising:

controlling a CGI engine to create a new CGI in response to determining the visual point of interest of the user, wherein the new CGI is for projecting as the refreshed CGI light and the new CGI includes information about the visual point of interest.

23. The method of claim **18** further comprising:

correcting the eye image data based on a transmission characteristic of the liquid crystal.

24. The method of claim **18** further comprising:

emitting the non-visible light onto the eye of the user with a near-infrared light source emitting near-infrared light centered between 800 and 1000 nm.

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